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COUNTING CRANES: HOW MUCH EFFORT IS ENOUGH?

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Abstract: Accurate population estimates of sandhill cranes (*Grus canadensis*) are important because management decisions, such as establishing hunting regulations, are based on those estimates. Counts often are made during aerial surveys when the cranes are congregated. A complete census may be feasible if the area to be surveyed is small and adequate resources are available. For large areas, resources may be inadequate for a census so partial counts (sample surveys) are made. Because cranes are gregarious, the counts in a sample of units may contain either a disproportionately large, or a disproportionately small, fraction of the total, leading to high variation among units and a very imprecise estimate of population size. Here we address the issue of survey accuracy by considering the Rocky Mountain population of greater sandhill cranes (*G. c. tabida*), which were surveyed each March in the San Luis Valley, Colorado. The entire population in the valley was surveyed for 12 years. We determined the accuracy of various sampling plans: these involved sampling fractions ranging from 20% to 50% to illustrate the potential for sampling a population that is spatially aggregated and to evaluate the feasibility of reducing the survey effort. We also compare systematic and simple random sampling and evaluate the efficacy of stratification. Our recommendations generally are pertinent to other populations of cranes, as well as other spatially aggregated species.

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Key words: aerial survey, census, Colorado, crane, *Grus canadensis*, population estimation, sample survey, San Luis Valley.

Considerable effort is expended each year in surveys of many species of birds. A rich variety of methods are available (Ralph and Scott 1981); which method is most applicable in any situation depends on the conspicuousness and behavior of the species, its habitat, availability of personnel and other resources, as well as other factors. Cranes (Gruidae) are of special interest: many species are threatened with extinction (Meine and Archibald 1996), some are subjected to recreational hunting, and most are popular with the public, so knowledge of population size and trends is particularly important. Two features typical of most crane species lend themselves to surveys, especially aerial surveys. First, cranes are large and conspicuous, so they are readily detectable. Second, they often congregate during some part of the year, typically on migrational staging areas or in winter.

Two very different spatial arrangements of cranes facilitate counting the birds. The first arises if all the cranes are *concentrated* in a known region that can be surveyed readily (Fig. 1). This situation renders feasible a *census* (i.e., total count) of the population. The second arrangement, and the extreme opposite of the first, occurs if the birds are *uniformly distributed* over some known region (Fig. 2a). In that case, if a sample of quadrats or transects is surveyed for the birds, each will have about the same density of birds (Fig. 2b). Then, *sample survey* methodology (e.g., Cochran 1977, Thompson 1992) will yield an estimated density with high precision.

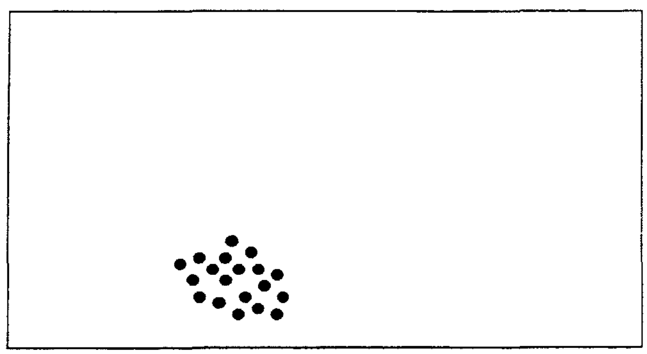

Fig. 1. One distributional pattern of cranes that is optimal for estimating population size is for them to be concentrated in a single area; this facilitates a complete census.

The ideal uniform distribution is never found in nature, of course, but the more evenly a population is distributed in space, the more accurate a sample survey estimator can be. Further, this ideal distribution can be more closely approximated by dividing the region into subregions (strata), within each of which the population is distributed more nearly uniformly.

Certain populations of cranes approach each of these spatial arrangements at some time during their annual cycle. The natural population of whooping cranes (*G. americana*)

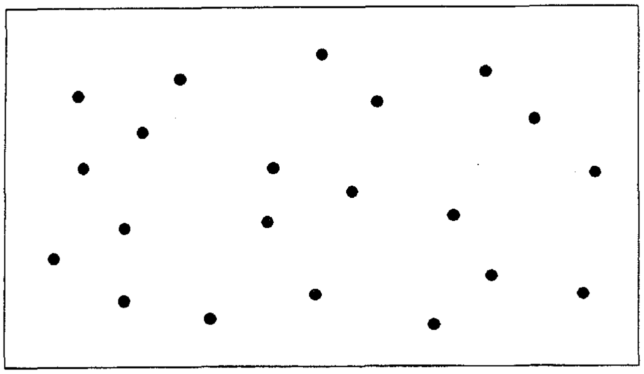

Fig. 2a. Cranes distributed almost uniformly, a situation opposite that in Fig. 1.

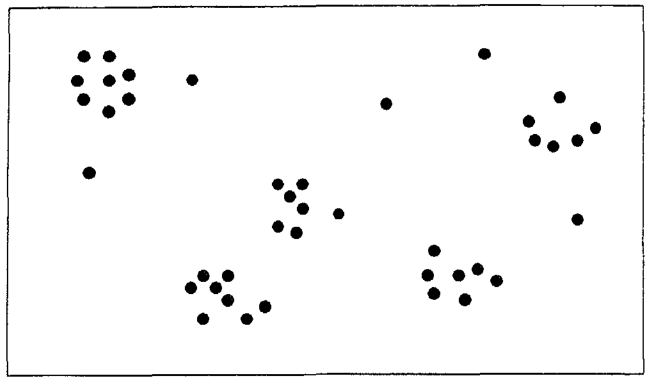

Fig. 3a. The least desirable arrangement for accurate estimates has cranes patchily distributed over a large area.

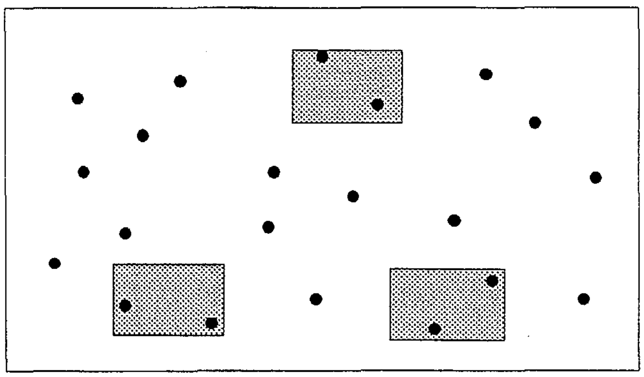

Fig. 2b. This arrangement is nearly optimal because transects or quadrats (shaded areas) are likely to have very similar densities of cranes, leading to sample survey estimates with high precision and accuracy.

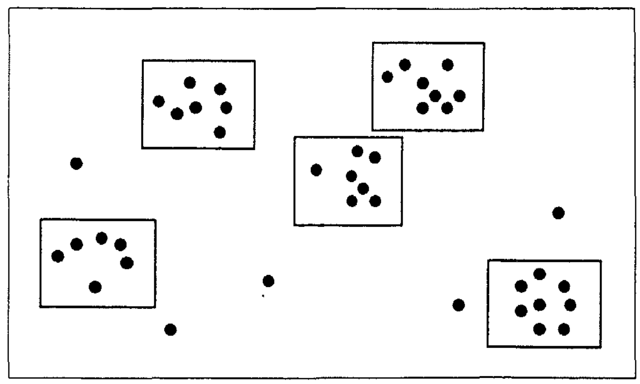

Fig. 3b. If the patches containing high densities of cranes (rectangles) can be identified *a priori*, stratification can be used to obtain more precise and accurate sample survey estimates.

winters in a relatively small and discrete area in southern Texas. That arrangement allows a virtually complete census to be conducted (Stehn and Johnson 1987). Birds that do not reach that wintering area or leave it before the survey will result in diminished accuracy of the estimate, but otherwise the counts are virtually exact.

Toward the other extreme, the midcontinent population of sandhill cranes (*Grus canadensis*) stages along the central Platte River Valley in Nebraska during spring migration (e.g., U.S. Fish and Wildlife Service 1981, Benning and Johnson 1987, Sharp et al. 1999). Although the birds are not uniformly distributed throughout that area, a stratification of the area renders sufficient homogeneity within strata so that resulting sample survey estimates typically have a standard error of about 12.6% of the estimated population size (D. H. Johnson, unpublished data).

Spatial arrangements intermediate between these extremes pose the greatest difficulty to determining population size (Fig. 3a). That is, if highly clumped distributions are not surveyed in their entirety, poor estimates result. However, if all aggregation sites are known prior to the survey, stratification is feasible and precise estimates are likely (Fig. 3b). An example of intermediate spatial arrangement involves the Rocky Mountain population of greater sandhill cranes (*G. c. tabida*), which stages in the San Luis Valley, Colorado, during spring migration (Drewien and Bizeau 1974, Benning et al. 1997). Aerial censuses of the population were conducted annually in all but one year during 1984–96. In actuality, the censuses were complete, but we use the data to exemplify the potential consequences of partial sampling from a clumped distribution.

The objectives of this paper are (1) to assess the variability in sample surveys of a highly clumped species, (2) to compare systematic sampling and random sampling, (3) to investigate the potential for stratification, and (4) to compare ratio estimates to estimates based on mean density. Our conclusions are based on the accuracy of various estimators of total population size; we do not consider estimates of precision, such as standard errors. We use results from aerial surveys of the Rocky Mountain population of sandhill cranes, but we project that many conclusions may be far more generally applicable.

METHODS

Survey Design and Field Methods

The Rocky Mountain population of greater sandhill cranes was aerially counted in March during 1984–91 and 1993–96 at its spring migration staging area in the San Luis Valley (Benning et al. 1997). (In 1992, only a ground survey was feasible.) Virtually the entire crane population assembles annually in early to mid-March in the San Luis Valley. This provides an opportunity to assess abundance before the population disperses throughout the Rocky Mountain region for the summer (Drewien and Bizeau 1974, Drewien et al. 1999).

The survey included 45 east-west transects totalling 1,263 km in length with a 1.6-km width (Benning et al. 1997). Individual transects varied in length from 1.6 to 40 km. Legal section lines were used as transect boundaries and generally were marked by roads, trails, or fence lines. Quarter-section lines were used as transect center lines. Each transect was subdivided into 1.6-km segments. The pilot used topographical features and global positioning systems to identify specific segments.

A fixed-wing, single-engine aircraft (Cessna 185) was used for all surveys (Benning et al. 1997). It was flown at about 160 km/hr ground speed and at an altitude of about 120 m above ground level to optimize visibility for observers. The pilot estimated crane flocks within 840 m of the aircraft on the left side and the observer did the same on the right side. Counts were made for each segment within each transect.

We made several simplifications in this analysis to focus on the main points. First, we restricted attention to the 42 (of 45) transects that were surveyed in all years (Fig. 4). Also, any cranes detected outside the established survey area were omitted. We did not perform adjustments for errors induced by inaccurate estimation of flock sizes. In the operational surveys, adjustments were made by comparing visual estimates with careful counts made from aerial photographs of numerous flocks and deriving correction factors separately for the pilot and the observer (Benning et al. 1997). For these reasons, the results in this report are not comparable to those in Benning et al. (1997) and should not be used for purposes other than the comparisons made herein.

For our comparisons, we used the following approach. For each sample, we computed the ratio estimate of the density. (An exception is our comparison of the ratio estimator to the mean-density estimator described below.) The ratio estimate is the total number of cranes counted divided by the total area surveyed:

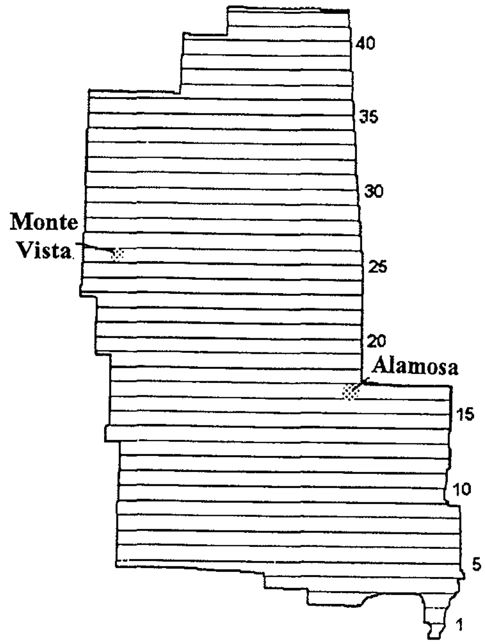

Fig. 4. Area of San Luis Valley, Colorado, where sandhill cranes were surveyed annually, 1984-96, showing the 42 east-west transects and the cities of Monte Vista and Alamosa.

$$\text{Ratio density estimator} = \frac{\sum \text{birds on transect}}{\sum \text{area of transect}}$$

The summations are over all transects in the survey. The density estimate was multiplied by the area of the entire survey area, 1904 km^2, to obtain an estimate of the number of cranes in the survey area. Estimates were compared to the true number in the survey area, the sum of counts made on all transects. The absolute value of the difference between an estimate and the true count, divided by the true count, was taken as a measure of inaccuracy.

Sampling versus Complete Census

We first considered various samples of the 42 transects, systematically chosen. Five of the samples represented 20%-sampling intensity (e.g., transects 1, 6, 11, etc.), 3 involved 33%-sampling intensity (e.g., transects 1, 4, 7, etc.), and 2 reflected 50% of the full effort (e.g., transects 1, 3, 5, etc.).

Systematic versus Simple Random Sampling

To compare systematic versus simple random sampling, we sampled from the 42 transects at the same intensities above (20%, 33%, and 50%). Twenty-five simple random samples were taken at each intensity level.

Stratification

We evaluated the effectiveness of stratifying the survey area with both a contiguous and a noncontiguous configuration of strata. In each case we formed 3 strata, which is a reasonable number relative to the number of transects (42). For both stratification schemes, we grouped transects into strata based on their densities during the first 5 years of the survey (1984–88) and evaluated the effectiveness of stratification with data from the subsequent 7 years. The contiguous stratification required that each stratum contain transects located together. Stratum 1, the southern part of the survey area, includes 12 transects that typically had low densities of cranes during 1984–88 (Table 1). Stratum 2, in the central portion of the survey area, includes 17 transects with mostly high average densities. Stratum 3 contains the 13 northernmost transects, most—but not all—of which had low average densities.

For evaluating stratification, we considered only the intermediate level of sampling intensity, 33%, incorporating 14 transects. We allocated the sample sizes to strata in an optimal manner (Cochran 1977), with the number of transects surveyed in each stratum proportional to the product of the total number of transects in the stratum (12, 17, and 13 for stratum 1 through stratum 3, respectively) and the sample standard deviation of densities during 1984–88 (1.25, 9.19, and 6.42, respectively). Rounded to nearest integers, the optimal sample size allocation was 1, 8, and 5. Note that stratum 1, with fairly consistently low densities, was sampled at the lowest rate. Stratum 2, with high and variable densities, received the most samples. Stratum 3, with mostly low but a few high densities, had an intermediate sampling intensity.

Although contiguous stratification is ordinarily done in surveys such as this (e.g., Benning and Johnson [1987] for the Platte River Valley), it is not necessary statistically, or even logistically, that transects in the same stratum be contiguous. With this greater flexibility of assigning transects to strata, one expects more homogeneity within each stratum, and thereby improved estimators. To establish noncontiguous strata, we sorted the transects according to average density during 1984–88 and grouped them into 3 strata. The result was stratum L, containing 25 transects with an average density <5 cranes/km^2; stratum M, with 8 transects having an average density between 5 and 12 cranes/km^2; and stratum H, including 9 transects that averaged >12 cranes/km^2 (Table 1). The optimal sample allocation was 3, 4, and 7 to strata L, M, and H, respectively.

Table 1. Mean densities of sandhill cranes (per km^2) in San Luis Valley, Colorado, 1984–88, by transect and by grouping of transects into contiguous (strata 1, 2, and 3) and noncontiguous (L, M, and H) strata.

Stratum		Transect	Mean density
Contiguous	Noncontiguous		
1	L	1	0.0
1	L	2	0.0
1	L	3	3.2
1	L	4	1.9
1	L	5	1.7
1	L	6	4.3
1	L	7	4.1
1	L	8	106
1	L	9	0.9
1	L	10	3.8
1	L	11	2.4
1	L	12	3.0
2	M	13	9.3
2	M	14	10.0
2	H	15	14.6
2	M	16	8.9
2	H	17	16.9
2	H	18	13.4
2	L	19	1.1
2	M	20	6.1
2	L	21	3.3
2	H	22	17.1
2	H	23	14.9
2	H	24	40.8
2	H	25	21.3
2	H	26	22.0
2	L	27	4.7
2	L	28	2.9
2	H	29	18.2
3	L	30	2.3
3	L	31	1.6
3	L	32	0.0
3	L	33	0.5
3	L	34	0.1
3	M	35	6.6
3	L	36	1.0
3	L	37	3.8
3	M	38	11.0
3	M	39	8.8
3	L	40	0.5
3	M	41	10.5
3	L	42	0.0

Ratio Estimator versus Mean-diversity Estimator

For comparison with the ratio estimator (e.g., Cochran 1977), we also calculated the mean-density estimator (Ferguson et al. 1979). The 2 estimators differ in the density estimators they use to multiply by total area. The ratio estimator (defined above) uses pooled counts of cranes and of transect areas. The mean-density estimator uses, as its name implies, the average of the density values:

$$\text{Mean density} = \frac{\sum \text{(Birds on transect/Area of transect)}}{\text{Number of transects}}$$

As before, the summation is over all transects in the survey. The density estimate was multiplied by the area of the entire survey area to obtain an estimate of the number of cranes in the survey area. We compared the 2 estimators under the scenarios of systematic sampling at 20%, 33%, and 50% levels, with 25 replications of each.

The ratio estimator has an advantage if transect lengths differ markedly and if longer transects are more likely to contain more birds than shorter transects. If those 2 conditions do not hold, the mean-density estimator typically performs at least as well as the ratio estimator and has a more straightforward estimator of its standard error.

RESULTS AND DISCUSSION

Sampling versus Complete Census

As expected, estimated counts based on samples differed from the true counts, often strikingly (Table 2). For example, consider sampling at the 20% rate in 1984. Five distinct samples were possible. Had sample 3 (transects 3, 8, 13, etc.) been drawn, the resulting estimate of 11,204 cranes would have been very close to the true value of 10,892. In contrast, had sample 5 (transects 5, 10, 15, etc.) been selected, the resulting estimate of 18,110 would have been 66% greater than the true value. The average error resulting from the 5 possible samples in 1984 was 27.6% of the true value.

Over all 12 years and all samples, estimates based on 20%-sampling fractions had an average absolute error of 38.9% of the true value. Estimates based on 33% of the transects averaged 19.6% error, and those based on 50% averaged 16.0% error. As the sampling intensity increased, estimates tended to approach more closely the true population size (Fig. 5).

That a complete census provides a more accurate count is certainly no surprise, but the wide variability in sample-survey estimates is surprising. We can contrast results from the San Luis Valley survey to those from the Patte River Valley survey. The Platte River Valley was not surveyed in its entirety, so we do not have the true population size or actual errors. We do, however, have estimated standard errors for each year. (For consistency with our analysis here of the San Luis Valley survey, we base the following comparisons on counts uncorrected for counting errors.) For the 10-year period 1989–98, the standard error of the counts averaged 12.6% of the population size (D. H. Johnson, unpublished data). That level of accuracy was obtained with only 15.3% sampling intensity.

Sample survey estimates should be reasonably accurate if the cranes are distributed in any modestly uniform manner. The huge variation among transects in average densities (Table 1) is vivid evidence that the cranes were not uniformly distributed.

Table 2. Range of estimates obtained with samples ranging from 20% to 50% of total versus true counts for sandhill cranes in San Luis Valley, Colorado, 1984–91 and 1993–96.

Year	True	Range of estimates for sampling fraction		
		20% (n = 5)	33% (n = 3)	50% (n = 2)
1984	10,892	7,286-18,110	10,634-11,153	9,687-12,095
1985	18,393	9,583-23,013	8,929-30,243	17,229-19,555
1986	13,412	9,552-15,401	7,907-17,646	8,803-18,026
1987	12,684	6,704-20,991	11,545-14,508	11,194-14,172
1988	17,496	9,698-35,099	12,783-20,976	17,093-17,900
1989	16,733	8,823-36,489	13,325-22,600	10,898-22,562
1990	19,923	10,457-40,102	18,273-21,780	15,532-24,319
1991	19,658	11,013-28,545	13,839-25,471	15,010-24,311
1993	16,529	7,060-34,570	12,405-24,288	15,504-17,552
1994	15,428	8,613-22,731	14,579-16,090	12,483-18,370
1995	24,658	8,800-58,544	17,769-32,550	24,171-25,144
1996	20,646	3,985-43,310	15,322-29,814	16,931-24,357

Systematic versus Simple Random Sampling

Simple random sampling performed nearly as well as systematic sampling for these data. Average absolute errors for simple random samples (an average from 25 simulations) were 37.2% of the true value at 20% sampling intensity (versus 38.9% for systematic sampling), 28.6% (versus

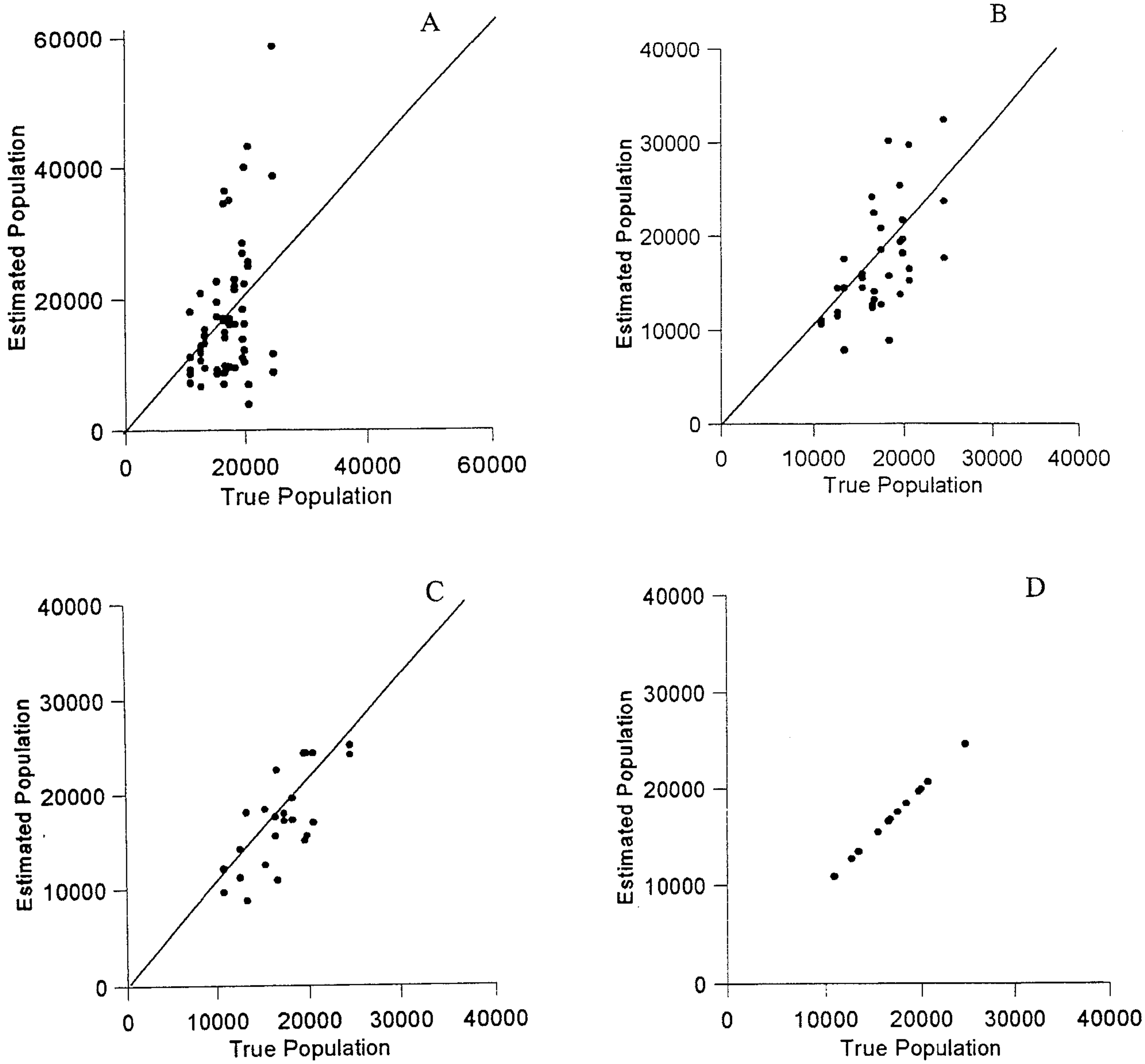

Fig. 5. Relations between estimates of population size and true population size, with systematic samples of (A) 20%, (B) 33%, (C) 50%, and (D) 100% of the transects. Diagonal lines represent perfect accord between estimated and true population size.

19.6%) at the 33% intensity level, and 19.7% (versus 16.0%) for the 50% sampling intensity level.

If there were a gradient in crane densities, with densities lower in the south and increasing to the north, then at equal sampling intensities a systematic sample is likely to be more accurate than a simple random sample. The latter sample could, by chance, include a disproportionate number of low-density transects, leading to a large underestimate or vice versa. A systematic sample would include both low- and high-density transects in proportions more similar to the true situation and thus yield a more accurate estimate.

Although we did not address standard errors in our analysis, it should be noted that, while simple random samples lead to straightforward estimates of standard errors, systematic samples do not (Cochran 1977). As a general rule, computing a standard error from a systematic sample as if it were from a simple random sample is a conservative approach. For example, a 95% confidence interval is likely to have true coverage greater than 95%.

Stratification

Stratification of the survey area into 3 contiguous strata, and taking random samples from each stratum, offered noticeable improvement over simple random sampling from the unstratified area. The average error for 1989–96 was 23.2% of the actual value. For comparable years, the average error was 31.1% for the simple random samples. The noncontiguous stratification produced negligible improvement over the contiguous stratification, with an average error of 23.0% of the actual value for 1989–96.

In general, stratification usually leads to improved estimates if transects within strata are more similar to each other than they are to transects from other strata. A typical advantage of stratification is smaller estimated standard errors. While stratification was of some benefit in the present situation, the improvement was not as much as would be expected if counts on transects were similar from year to year. In fact, the correlation between counts on the same transect in successive years was only 0.51, indicating the limited consistency from year to year in areas used by the cranes.

Ratio versus Mean-density Estimators

For the situations we examined, systematic sampling at 3 levels of intensity, the ratio and mean-density estimators performed nearly equally well. Average errors for the ratio estimator and mean-density estimator, respectively, were 38.9% and 37.0% under 20% sampling intensity, 19.6% and 20.9% with 33% sampling intensity, and 16.0% and 16.2% with 50% sampling intensity.

The nearly equivalent performance of the ratio estimator and the mean-density estimator was not unexpected. We have had similar findings with the Platte River Valley survey of sandhill cranes for a number of years (D. H. Johnson, unpublished data). If cranes were more uniformly distributed, then longer transects would more surely have more cranes, and the ratio estimator would be expected to bew more accurate. As it is, cranes are distributed in a more clumped fashion, and longer transects may not necessarily contain more cranes than shorter transects (in the San Luis Valley survey, the correlation between length and count averaged only $r = 0.22$ for the 12 years). In that situation, the mean-density estimator performs well. In addition, the standard error of the mean-density estimator can be calculated more directly than that of the ratio estimator, which involves a large-sample approximation (Cochran 1977).

CONCLUSIONS

Locations of cranes in the San Luis Valley were not consistent from 1 year to another; the correlation between counts in successive years on the same transect was a modest 0.51. Cranes no doubt were responding to changes in land use, foraging opportunities, weather conditions, human activities, and other influences that may vary unpredictably from year to year. The dynamic nature of crane distribution in the San Luis Valley suggests that sample surveys, even at fairly intensive rates, may provide very misleading estimates. This conclusion was borne out in our comparisons of sample survey results with complete censuses.

While the results of our analyses pertain specifically to the Rocky Mountain population of sandhill cranes, the inferences have broader application. Surveys of other populations of cranes, as well as of other species such as geese, likely are subject to similar concerns. It is essential to understand the behavior of the birds and the habitat they use to design an adequate census or survey. Differences between the San Luis Valley and the Platte River Valley, notably in the patchiness of habitats used by sandhill cranes, explain why a modest sample survey is satisfactory for the latter but woefully inadequate for the former. For the very patchy distribution typical of the San Luis Valley population (and for similar situations with other populations and other species), it is evident that a reasonable estimate will require that a large fraction of the area be surveyed. If most of the area must be sampled, it is nearly as feasible to conduct a census covering the entire area.

Although a census is certainly better than a sample survey, especially in the situation examined herein, it is critical that managers look for long-term patterns, rather than base decisions on results from only a few years. For example, the change in true population from 1984 to 1985, from 14,112 to 20,382 (Fig. 6), is biologically impossible (without extreme immigration). (Note: these comparisons use the operational estimates, involving corrections for estimation error, removal of cranes thought not to belong to the Rocky Mountain population, and inclusion of cranes located outside the survey area at the time of the survey [Sharp et al. 1999].) Equally implausible is the subsequent decline in 1986 to 13,155 birds. Blind faith in population estimates for one or a few years, even those with small standard errors, can be dangerous.

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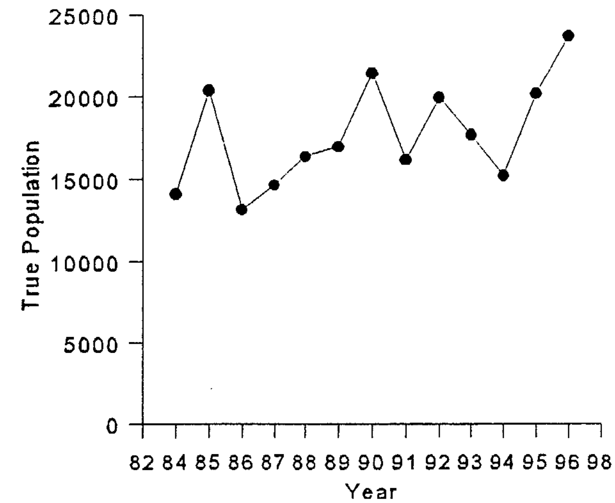

Fig. 6. Estimated size of Rocky Mountain greater sandhill crane population. This model incorporates corrections for counting error, for cranes outside San Luis Valley at time of survey, and for cranes in San Luis Valley, Colorado, that did not belong to Rocky Mountain population (from Benning et al. 1997).

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